Characterization of a Hard-Switching Motor Controller for EMC Considerations

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SSC San Diego

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ADMINISTRATIVE INFORMATION

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INTRODUCTION

The Office of Naval Research (ONR) Power Electronics Building Block (PEBB) Program is developing metal-oxide semiconductor (MOS)-Controlled Thyristors (MCTs) for advanced shipboard electric power distribution systems. An essential element of the PEBB is the control and monitoring circuitry that enables "smart power." Integration of the control circuitry into a common substrate with a power electronic device such as the MCT should improve system performance. Fewer wire bonds and printed circuit board (PCB) interconnects would increase reliability. Cost, size, and weight would be reduced through more integration and less packaging.

However, bringing together both low-power control circuitry and high-power switching circuitry into a common substrate or restricted volume raises the possibility of electromagnetic interference (EMI). Furthermore, the installation of the high power and high switching speed PEBB devices in a shipboard environment will increase the possibility of conducted EMI in the shipboard power distribution system. The collocation of the sensitive PEBB devices with other high-power radio-frequency (RF) communication and radar systems 4ill also raise radiated EMI issues. The electromagnetic compatibility (EMC) issues concerning the PEBB device level, PCB level, box (sub-system) level, and power distribution system level are listed in the following paragraphs.

At the PEBB device level, the EMC issues are:

- Characterizing the PEBB device for EMC considerations through modeling and an equivalent circuit approach. Feasibility and cost-effectiveness of this approach must first be considered.

- Developing tests or standards for EMC considerations at the PEBB device level.

- Determining how close PEBB switching circuitry and control circuitry can be collocated.

- Designing the PEBB device to reduce EMI. (Soft switching and choosing parameters of the driving circuit to reduce coupling are two techniques discussed by Divan (1996) and Hockanson et al. (1996), respectively.)

At the PCB level, the EMC issues are:

- Integration of high-power, high-speed, small-size PEBB onto a board or into other small-volume packaging.

- Adequacy of current PCB design techniques for PEBB design, such as those discussed by M. I. Montrose (1996). Current reduction of EMI on PCB is an active research area, but has generally been considered only for low-power circuits.

- Use of current PCB EMI-reduction design techniques in PEBB design.

- Development of tests or standards for EMC considerations at the PCB level.

At the PEBB box (sub-system) level, the EMC issues are:

- Characterization of the PEBB "box" for EMC considerations through measurements and modeling.

- Application of EMC standards (such as MIL-STD 461, 462, 463 or new Federal Communications Commission, Department of Commerce, or European commercial standards) to the PEBB box.

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At the power distribution system level, the EMC issues are:

- Possibility that distributed current (DC) ground bus common mode coupling may cause fluctuation of ground voltage and EMI in DC Zonal Electrical Distribution System (ZEDS).

- Consideration of the desired (or current) quality of navy shipboard power distribution systems. The factors for consideration include desired (or current) capability of the voltage regulator on the ship, stability of the power distribution system, transients caused by high-speed, high-power switching, fault detection and isolation, dynamic changing of load demand, and zoning for damage control.

- Establishing the conductive EMC requirements for achieving the desired quality of power distribution systems.

- Establishing the acceptable radiated emission and susceptibility levels for PEBB and other shipboard RF equipment.

This list of EMC issues is not complete. Other EMC considerations may exist that are not listed above. Other PEBB program team members are probably addressing some of these EMC problems. In FY 1997 and FY 1998, SSC San Diego received funding to start addressing the important issue of determining the acceptable radiated emission and susceptibility levels for PEBB and other shipboard RF equipment. This effort was initiated in May 1997.

This research effort addresses the 1997 Science and Technology Requirements Guidance (STRG), issued by the Office of the Chief of Naval Operations, N091, in July 1997 under Chapter 4, Surface Warfare, Section 6, Ship Design for Enhanced Warfighting, as follows: "Develop technologies to reduce a ship's vulnerability to weapon impact through the use of various technologies, possibly including integrated power systems." This research effort also addresses the ONR Guidance for FY 1998 Surface Ship HM&E Proposal Preparation (ONR ltr. ser: 334/112/ajt of July 1997), under Power and Automation Thrust Area, Submarine and Ship Platform Tasks, Power Electronic Components, as follows: "Electromagnetic susceptibility/compatibility of high-frequency power converters."

OBJECTIVE

The overall objective of this research is to characterize Power Electronic Building Blocks (PEBBs) for application of electromagnetic compatibility (EMC) in existing and advanced shipboard electric power systems. Both emissions and susceptibility levels will be studied, first for radiated EMI and later for conducted EMI. The EMI suppression techniques in large and small high-density power electronic modules will be developed.

This document presents the results of the initial efforts toward the overall research objective. These initial efforts include setting up the EMI measurement facilities, developing EMI measurement techniques, and performing radiated emission tests on a motor controller, which is a hard-switching device.

EMI MEASUREMENT FACILITIES

SSC San Diego started to construct a building and purchase and set up the measurement facilities in May 1997. The EMI measurement facilities include the EMCO Gigahertz Transverse Electromagnetic Mode (GTEM) cell, converter, cooling system, filters for power lines, and signal generators.

The building construction and installation of the EMCO Gigahertz Transverse Electromagnetic Mode (GTEM) cell were completed in October 1997 (figures 1 through 5).

The GTEM cell is a field-generating device that represents a significant advance in state-of-the-art EMC testing. It characterizes PEBB for application of EMC in existing and advanced shipboard electric power systems. Measurement techniques for radiated emission and susceptibility levels for PEBB and other shipboard RF equipment can be developed. Acceptable radiated emission and susceptibility levels for PEBB and other shipboard RF equipment can be established.

The GTEM provides a controlled, low-ambient environment for quickly performing both emissions and immunity testing in the same cell with minimal change in the test setup. The usable bandwidth is DC to 20 GHz for immunity testing and 9 kHz to 5 GHz for emissions testing. Typical voltage standing wave ratio (VSWR) is less than or equal to 1.5:1. The model 5317 GTEM cell weighs 1984 pounds and is 25.3 feet in length, 10.2 feet in height, and 13.5 feet in width. The GTEM cell setup can be adapted to either time or frequency-domain measurements that would include but not be limited to:

- Effects of controlled field on test objects

- Calibrated field measurements emanating from a test object

- Transmission and reflection measurements of materials

- Radar-cross-section (RCS) measurements

SSC San Diego provided a tour of the GTEM cell measurement facilities and EMC analysis models at the SSC San Diego Model Range for the attendees of the Power Electronics Applications Workshop, San Diego, California, 5–7 November 1997. The GTEM cell information, including door dimensions, working volume, a photo of the GTEM cell, and test equipment was sent to Naval Surface Warfare Center/Carderock Division (NSWC)/CD Annapolis Detachment in January 1998. SSC San Diego built three dipole probes for GTEM cell calibration in May 1998. The calibration test was completed in June 1998.

A DC power supply purchased from Dynapower Corporation was received in December 1997. The power supply is a DC-output, 12-pulse, secondary thyristor-controlled power supply (figure 6). The input power of the power supply is 305 kVA, 390 amperes, 450 V, three-phase, 60 Hz. The output voltage ranges from 0 to 900 VDC, and the output current ranges from 0 to 300 amperes. The power supply provides DC input power for PEBB test units. Installation and connection of electricity to the DC power supply were completed in February 1998.
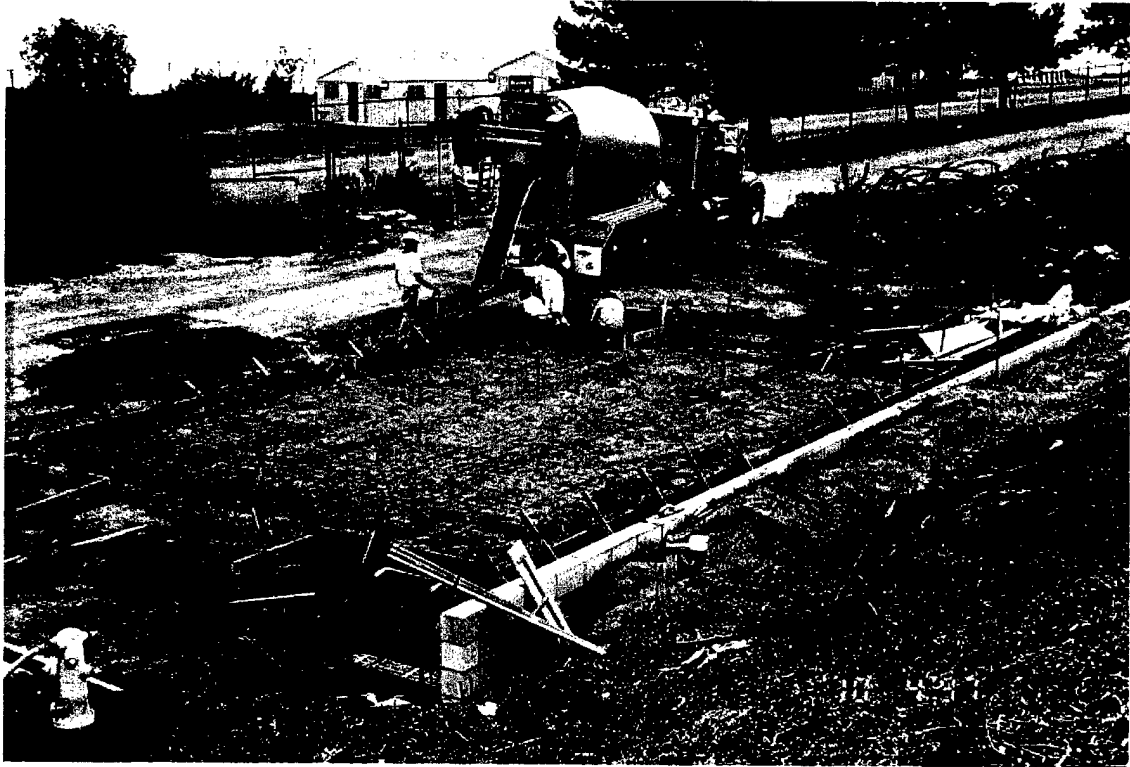
Figure 1. Pouring foundation for new PEBB/GTEM measurement facility.
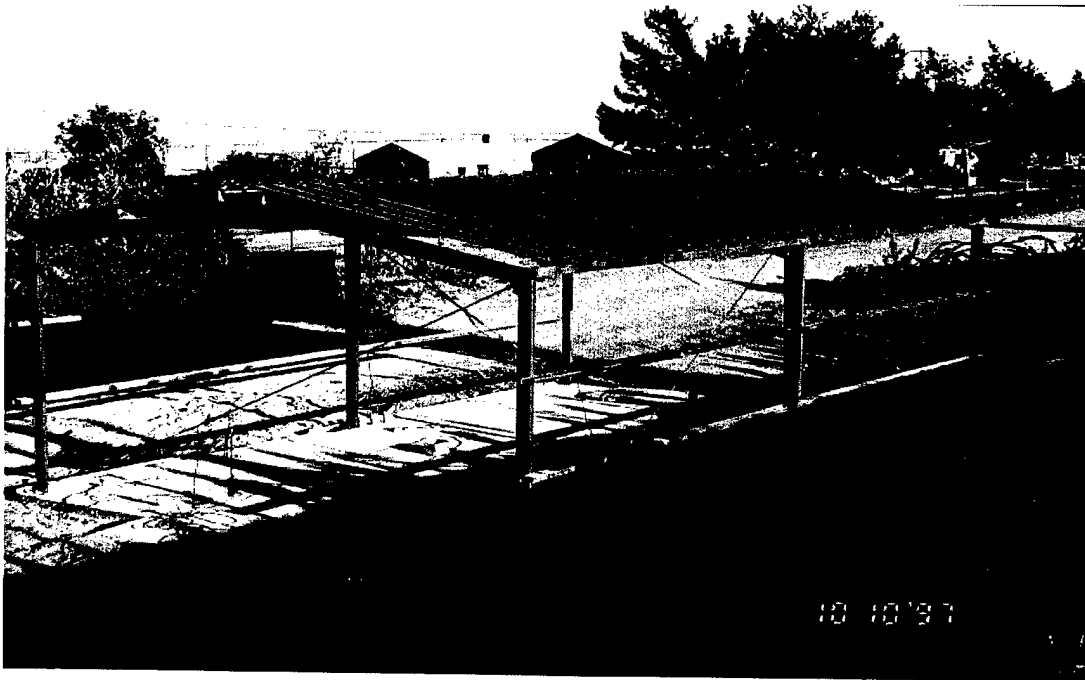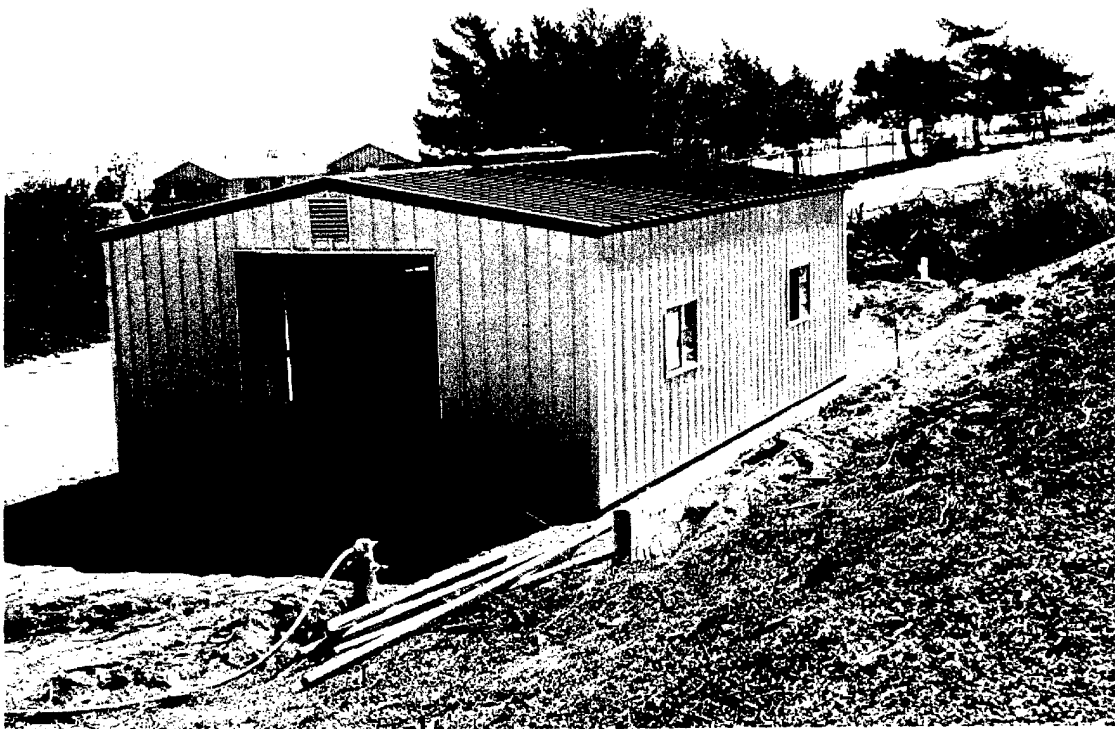

Figure 2. Constructed framework and roof.

Figure 3. Completed GTEM building.

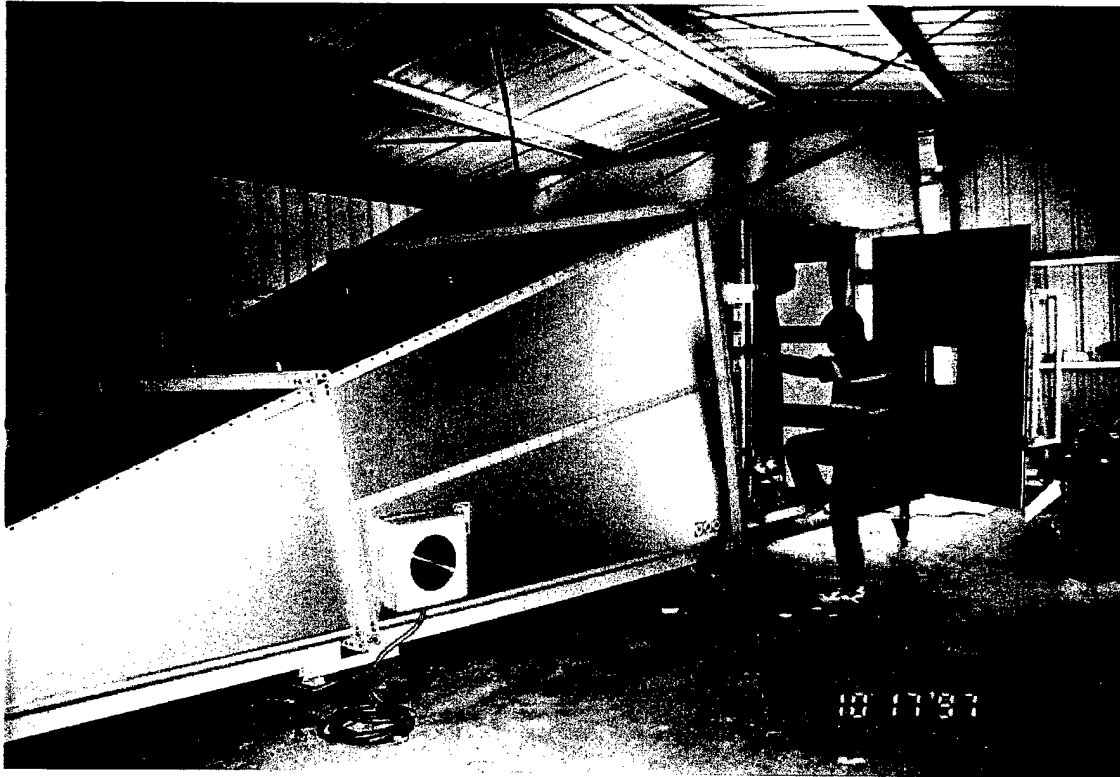Figure 4. Construction of GTEM cell.
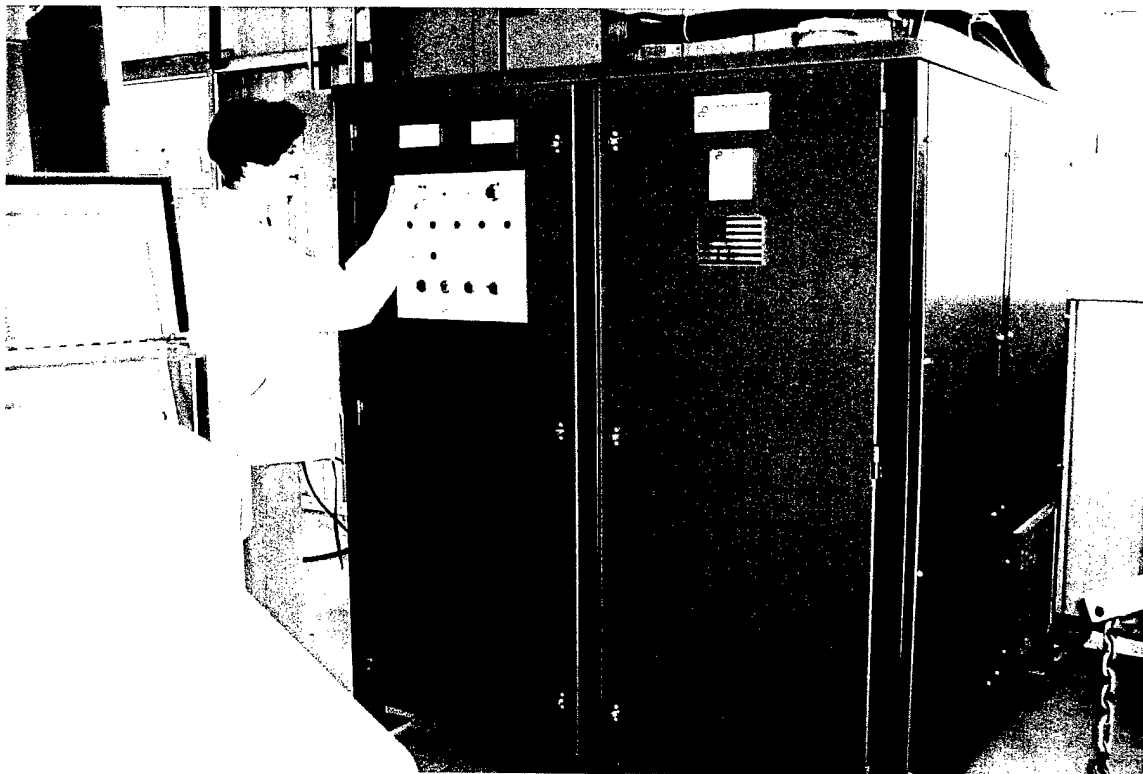
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Figure 5. Completed GTEM cell

Figure 6. DC power supply.

Installation and connections of water source and electricity to the water-cooling unit for the PEBB testing unit from Bay Voltex Corporation were completed in February 1998. Figure 7 shows the water-cooling unit installed outside the building.
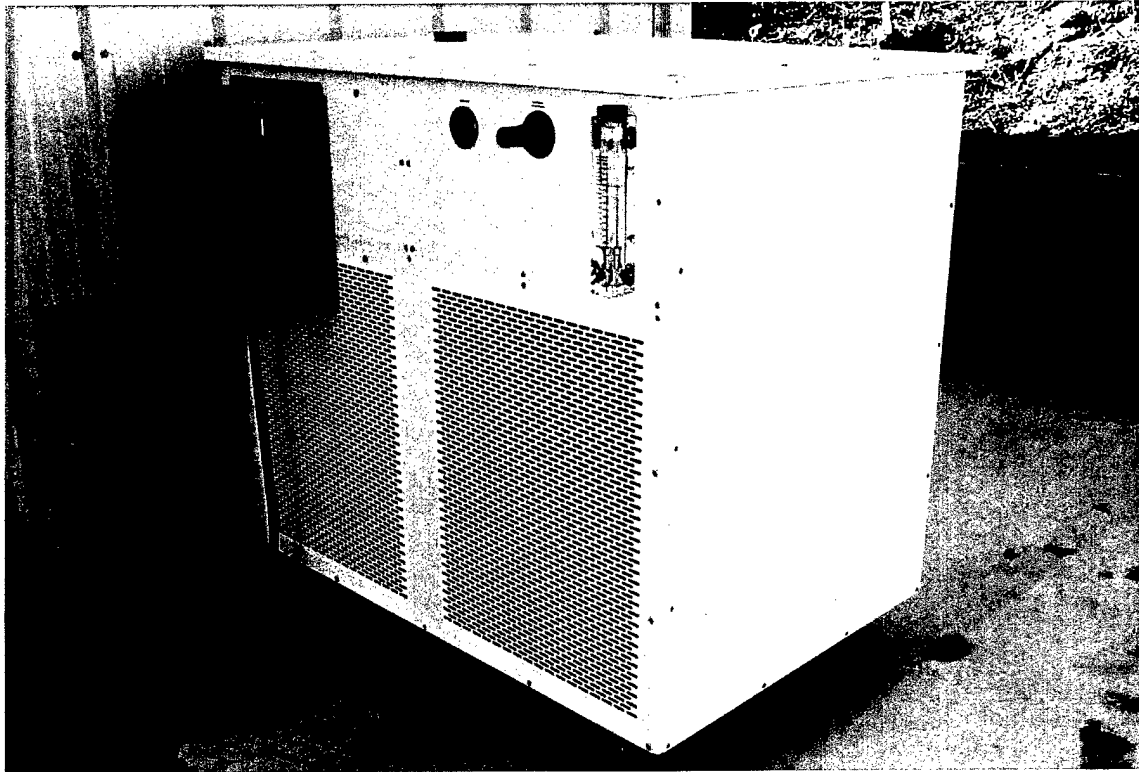
Figure 7. Water-cooling unit.

In March 1998, the NSWC/CD Annapolis Detachment informed SSC San Diego that they will not be able to lend a load bank to SSC San Diego because the load bank was too old and fragile to ship to San Diego. SSC San Diego decided to purchase a Dynamite 400 (D400) load bank from Simplex, Inc. The D400 allows the operator to apply resistive only load steps with 5-kW resolution at unity power factor, with a maximum load of 410 kW at 240 or 480 VAC, three-phase. It can be used at any voltage to 480 VAC, 50 or 60 Hz, single- or three-phase. The D400 is not suitable for DC load testing. SSC San Diego received the D400 load bank in June 1998. Figure 8 shows the D400 load bank.

Figure 8. Resistive load bank.

SSC San Diego received a three-phase, 600 VAC, 300-Amperes, power-line EMI filter from Potter Production Corporation in June 1998. Installations and connections of electricity to the power-line EMI filter and to the D400 load bank were completed in September 1998. Figure 9 shows the power-line EMI filter.
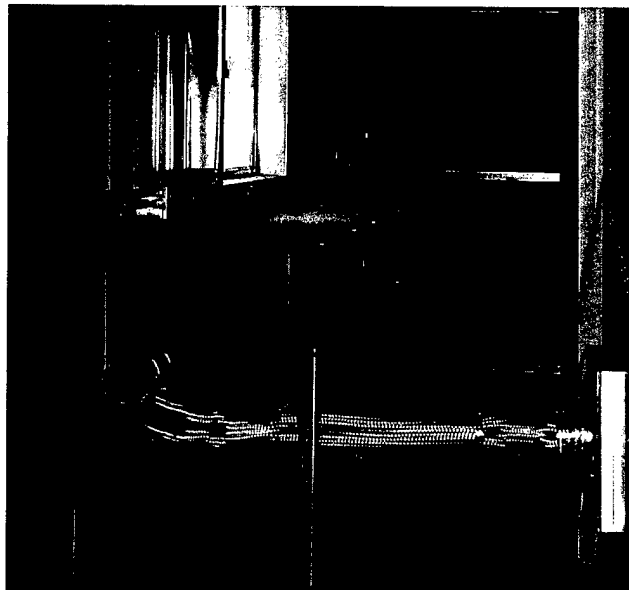

Figure 9. EMI filter.

SSC San Diego made plans with the NSWC/CD Annapolis Detachment to obtain a PEBB unit for testing. In March 1998, the NSWC/CD Annapolis Detachment recommended that SSC San Diego first test Reliance Electric's GP2000 A-C variable-speed controller for a 125-HP motor before testing a PEBB unit. This recommendation changes the measurement facility setup from a DC power supply to an AC power supply. In April 1998, SSC San Diego visited the NSWC/CD Annapolis Detachment to discuss the testing of Reliance Electric's motor controller. In July 1998, SSC San Diego received a Reliance Electric motor controller for testing.

A plan for equipment grounding connections of all measurement facilities (building and test article) was made in August 1998. Equipment grounding connections were completed in September 1998. The measurement facility is complete. The GTEM cell calibration, measurement techniques for establishing acceptable radiated emission levels for Reliance Electric's motor controller, and measurement results are discussed in the next sections.

GTEM CELL TRANSFER FUNCTION

This section describes the derivation of a GTEM cell transfer function and how the transfer function is used for GTEM cell calibration.

DERIVATION OF TRANSFER FUNCTION

Figure 10 shows the equivalent circuit of the GTEM cell. The measured voltage, V, across the terminating resistor, R_T, is related to the electric field by the effective height, h_{eff}, of the cell acting as an antenna.
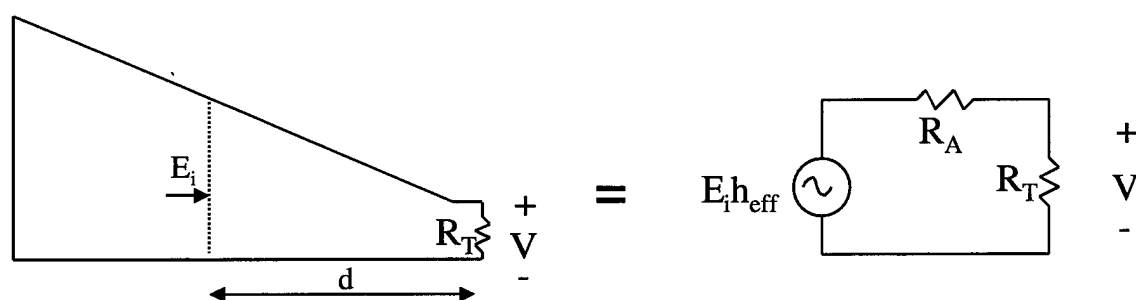
E_i = GTEM electric field at location of EUT

R_A = resistance of GTEM cell

R_T = resistance of termination

h_{eff} = effective height of GTEM as an antenna

Figure 10. GTEM equivalent circuit.

The equation for effective height of an antenna is provided by J. D. Krause (1950):

$$h_{eff} = \sqrt{\frac{A_e(R_A + R_T)^2 + (X_A + X_T)^2}{120\pi R_T}}$$

where $R_A + jX_A$ is the impedance of the GTEM cell, $R_T + jX_T$ is the impedance of the termination, and A_e is the effective aperture. Since $X_A = X_T = 0$ and $R_A = R_T = 50\ \Omega$, this equation simplifies to

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$$h_{eff} = \sqrt{\frac{100^2 \, A_e}{50 \, (377)}}$$

$$h_{eff} = .73 \sqrt{A_e} \; .$$

The effective aperture is defined as $G\lambda^2/4\pi$, so the effective height of the GTEM may be rewritten as

$$h_{eff} = .73 \sqrt{\frac{G\lambda^2}{4\pi}} \; ,$$

where G is the gain of the GTEM cell. The effective height simplifies to

$$h_{eff} = .206\lambda \sqrt{G} = \frac{61.8 \sqrt{G}}{f_{MHz}} \; .$$

The generated voltage is divided between the cell's radiation resistance and the terminating resistance, R_T. The voltage measured at the GTEM output is therefore given by

$$V = E_i \, h_{eff} \frac{R_T}{R_T + R_A}$$

$$V = \frac{E_i \, h_{eff}}{2}$$

$$E_i = \frac{2V}{h_{eff}} = \frac{2 \, V f_{MHz}}{61.8 \sqrt{G}} = \frac{32 \, V f_{GHz}}{\sqrt{G}} \; . \tag{1}$$

The gain of the GTEM cell is determined in the following section to have a value of 10.5. Therefore, the transfer function may be rewritten as

$$E_i = 10V \, f_{GHz} \; . \tag{2}$$

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GTEM CELL CALIBRATION

Figure 11 shows the setup used to calibrate the GTEM cell. A half-wave dipole antenna was placed inside the cell at a distance, d, from the feedpoint. The voltage at the feedpoint was measured for a power of 10 mW into the dipole. This procedure was repeated for three frequencies, using appropriately sized dipole antennas.
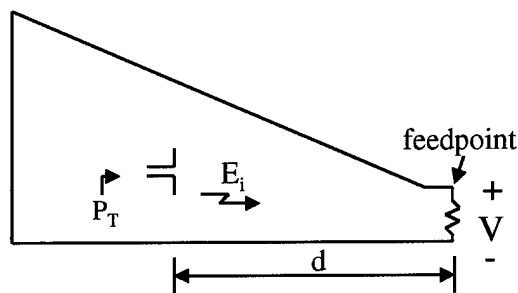

Figure 11. Calibration of GTEM cell.

The radiated electric field from a half-wave dipole (or a quarter-wave monopole) driven by the power, P_T, is provided in the *Reference Data for Radio Engineers* (IT&TC,1975):

$$E_i = \frac{\sqrt{49.2\, P_T}}{d}. \tag{3}$$

To relate the field inside the GTEM to that generated by a half-wave dipole, the field in equation (1) is equated to the field in equation (3). Solving for the measured voltage yields

$$V = \frac{\sqrt{49.2 P_T\, G}}{32\, d\, f_{GHz}} = \frac{.22 \sqrt{P_T\, G}}{d\, f_{GHz}}. \tag{4}$$

Equation (4) allows the voltage received at the output of the GTEM to be related to the radiated power from a half-wave dipole at a distance, d, from the apex (feedpoint) of the GTEM. This equation was used to calibrate the GTEM cell with half-wave dipole antennas (figure 11). The measured results appear in table 1.

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Table 1. GTEM calibration measurement values.

Frequency	Power into dipole (W)	Distiance, d (meters)	GTEM Power Out (dBm)	GTEM Output Voltage (V)
234	0.01	4.87	-11.2	0.0614
464	0.01	4.87	-17.1	0.0309
923	0.01	4.87	-23.1	0.0156

The measured data points agree with the equations derived here for a GTEM gain of 10.5. The measured points have been superimposed on the bottom calibration line in figure 12, for which the equation is given by

$$P_{GTEM} = 10\log\left[\left(\frac{.7\sqrt{P_T}}{d\,f_{GHz}}\right)^2 \Big/ 50X10^{-3}\right],$$

where P_{GTEM} is in dBm, P_T in watts, d in meters, and f_{GHz} in Gigahertz.

Figure 12 is a graph showing the measured calibration points at 234, 464, and 923 MHz. The calibration line can be extrapolated to the lower frequencies by a 6-dB-per-octave slope. The bottom line represents the power at the output of the GTEM for a 10-mW input to a tuned dipole located 4.87 meters from the GTEM apex. Parallel lines have been drawn at 10-dB separations to indicate similar information for 10-mW and 1-W input power levels to obtain a complete calibration set. Equation (4) shows the relationship between the output voltage at the apex of the GTEM to the power into a tuned dipole inside the GTEM located *d* meters from the apex. Equation (4) was obtained by equating the electric field generated by a tuned dipole to the GTEM electric field transfer function to determine the output voltage produced at the GTEM apex.
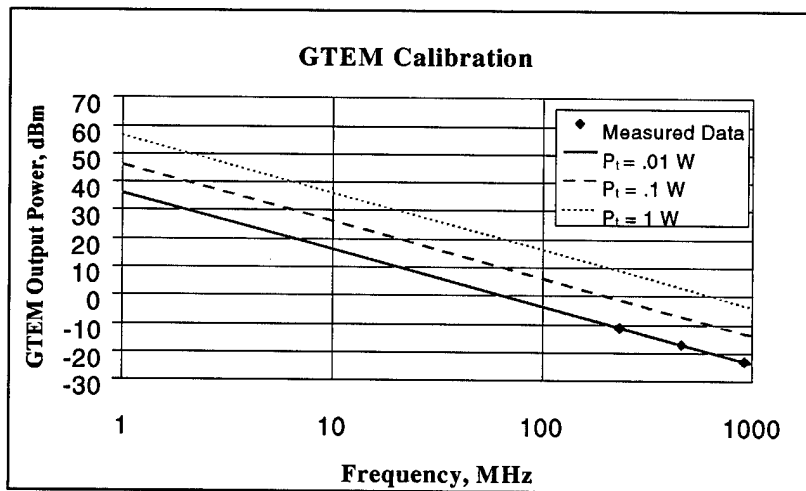

Figure 12. Calibration data relating GTEM output power to power into dipole.

MEASUREMENT TECHNIQUES USING THE GTEM CELL

The EMCO Model 5317 GTEM cell (figure 13) is a device that can be used for radiated emissions (RE) tests in the 9-kHz to 5-GHz frequency range, or radiated interference (RI) (susceptibility) tests in the DC to 20-GHz range. The radiated emissions tests are conducted by placing the equipment under test (EUT) in the GTEM cell and operating the equipment in some predetermined mode. The voltage measured at the GTEM output is related to the radiated field emitted by the EUT by equation (2) derived in the previous section:
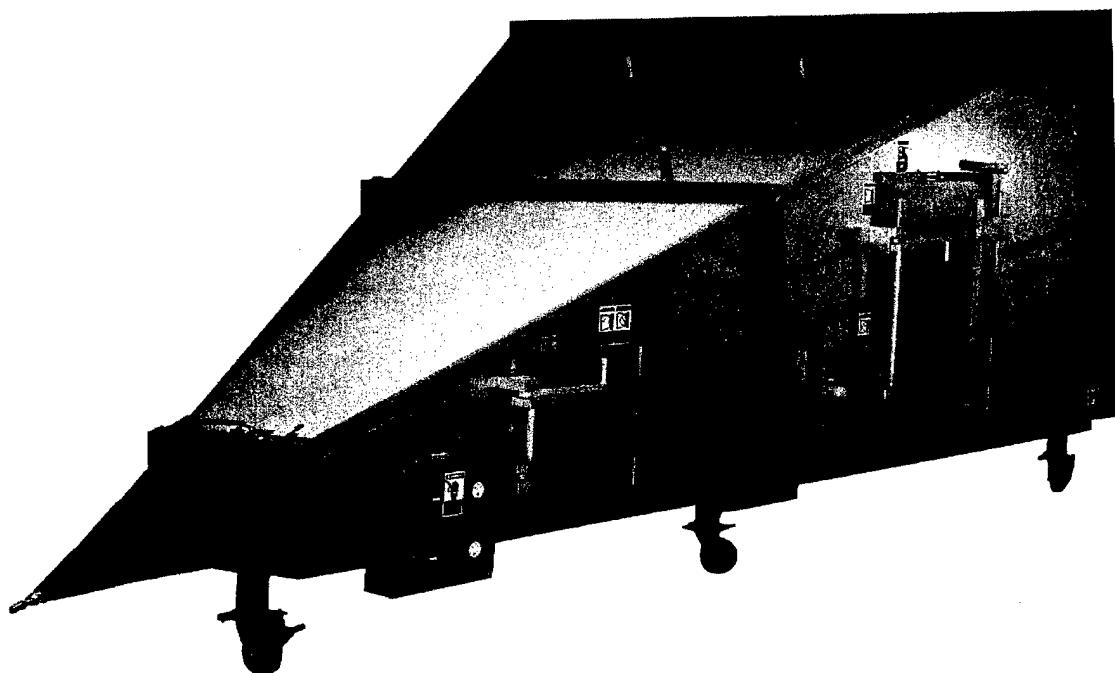
$$E_i = 10 \text{ V } f_{GHz} .$$

Figure 13. GTEM cell.

TEST SETUP

Figure 14 shows the basic setup that was used for testing the Reliance Electric motor controller, which is the basic setup for an EUT operating on AC power. Figure 15 is the test setup that will be used for a DC-powered EUT such as the PEBB. Note the different locations of the EMI filter and the load bank.

The Reliance EUT (figure 16) was placed in the GTEM cell. The Reliance EUT was operated with a 50-kW load for the initial test. The Simplex load bank was set to be a 50-kW resistive load to the Reliance unit. The Reliance unit was operated according to the procedure outlined in the equipment's operating manual.
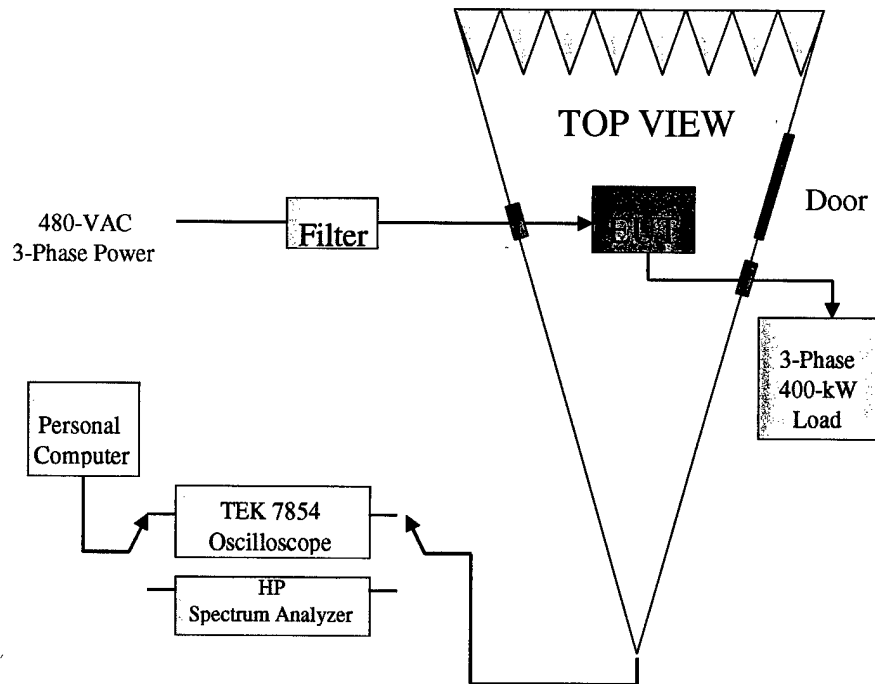
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TOP VIEW

480-VAC
3-Phase Power → Filter → [EUT] Door

3-Phase
400-kW
Load

Personal
Computer

TEK 7854
Oscilloscope

HP
Spectrum Analyzer

Figure 14. Test setup for AC-powered EUT.

TOP VIEW

Water-
Cooling Unit

Door

3-Phase
400-kW
Load Bank ← Filter ← [EUT]

AC Out

DC Power
Supply
0-900 V
300 A

Personal
Computer

TEK 7854
Oscilloscope

HP
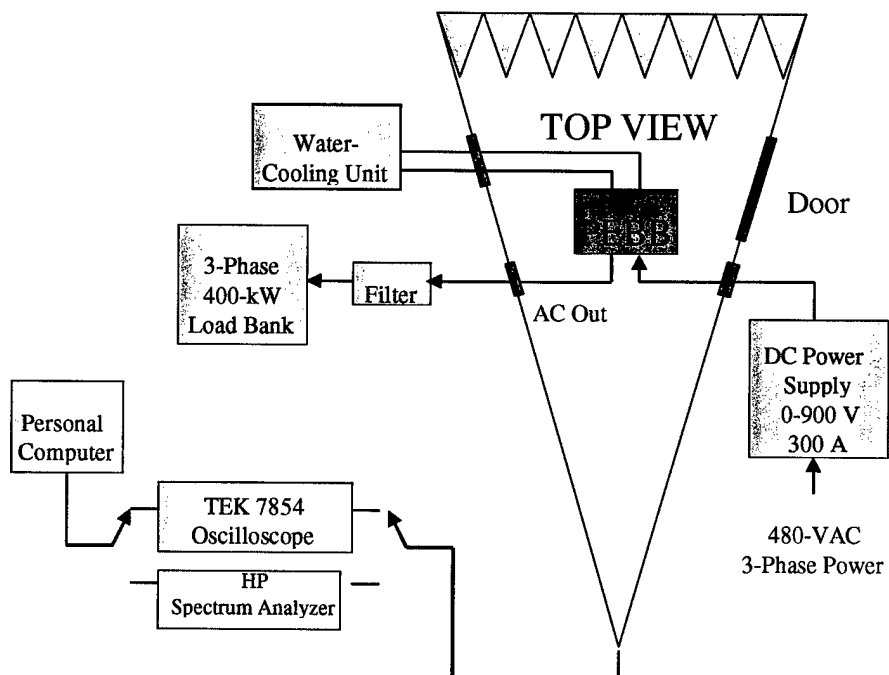Spectrum Analyzer

480-VAC
3-Phase Power

Figure 15. Test setup for DC-powered EUT.

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Figure 16. Test Article: Reliance Electric Motor Controller.

TEST PROCEDURE

The diagram in figure 17 shows that both a sampling oscilloscope and a spectrum analyzer measured the emissions generated by the operating Reliance unit. For the oscilloscope measurement, the voltage waveform was captured as a function of time, then transferred to a personal computer (PC). A Fast Fourier Transform (FFT) was performed on the waveform. The PC then performed the mathematical manipulations necessary to present the oscilloscope data in the same format as the spectrum analyzer data (power in dBm versus frequency). The converted oscilloscope data are then compared in amplitude to the spectrum analyzer data and the difference noted. This difference is then used to generate a correction factor that is then applied to the original time-domain amplitude data obtained from the oscilloscope. This correction is necessary because when the sampling oscilloscope averages the time waveform generated by the Reliance unit, the amplitude and phase variations in the time waveform cause the averaged waveform to decrease in amplitude significantly. This correction would not be necessary for stable waveforms. The corrected time waveform can then be used to determine the Reliance Motor Controller's time-domain electric field emissions.
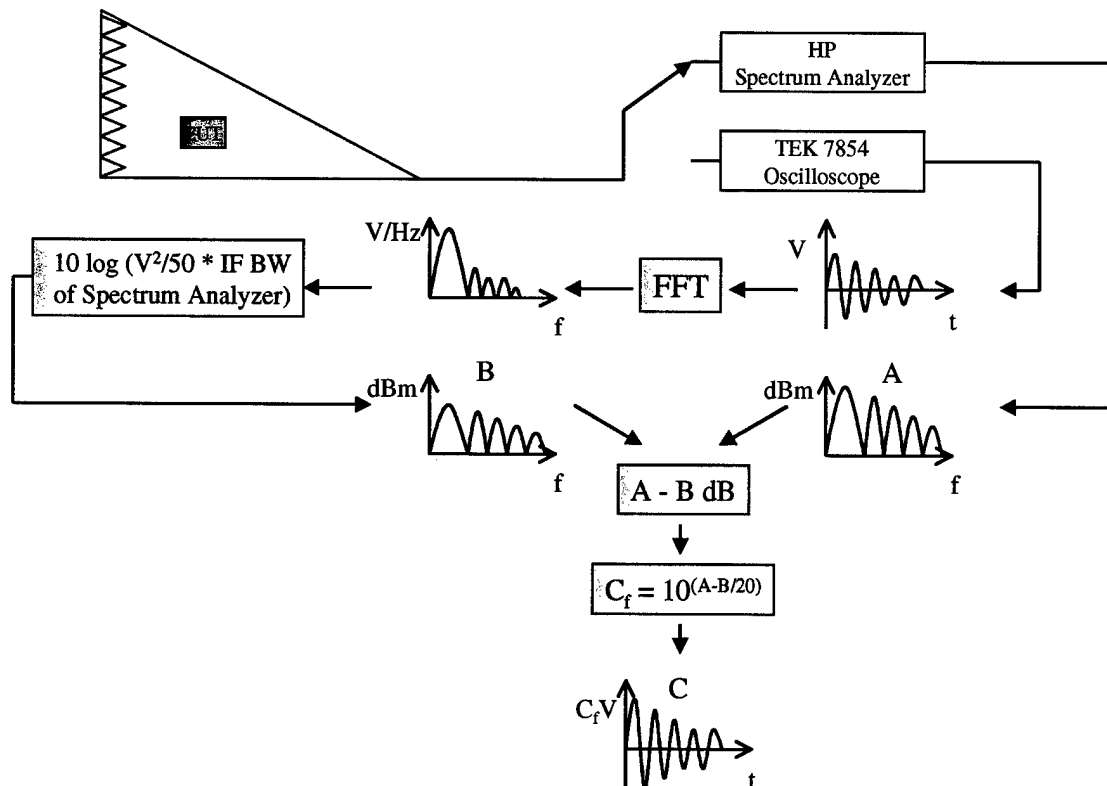
Figure 17. Determination of time-domain correction factor.

ELECTRIC FIELD FROM FREQUENCY-DOMAIN DATA

Figure 18 shows how the spectrum analyzer data are operated upon to obtain the electric field data. The measured spectrum analyzer data (power, P, in dBm versus frequency) is converted to a voltage, V, versus frequency spectrum. This waveform is then multiplied by the GTEM transfer function (equation 2) to obtain the electric field intensity versus frequency. The measurement bandwidth of the spectrum analyzer (10 kHz) must be considered in calculating the amplitude of the electric field intensity. Since the data were taken in a 10-kHz bandwidth, 40 dB has to be added to the amplitude to adjust it to the 1-MHz bandwidth normally used as a measure of broadband EMI. Figure 19 shows the electric field in decibels relative to 1-μVolt/meter in a 1-MHz bandwidth (dB(μV/m)/MHz) as a function of frequency.
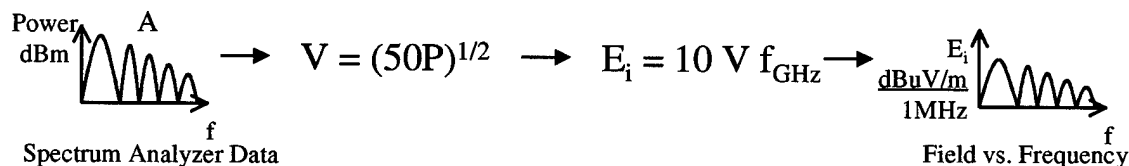

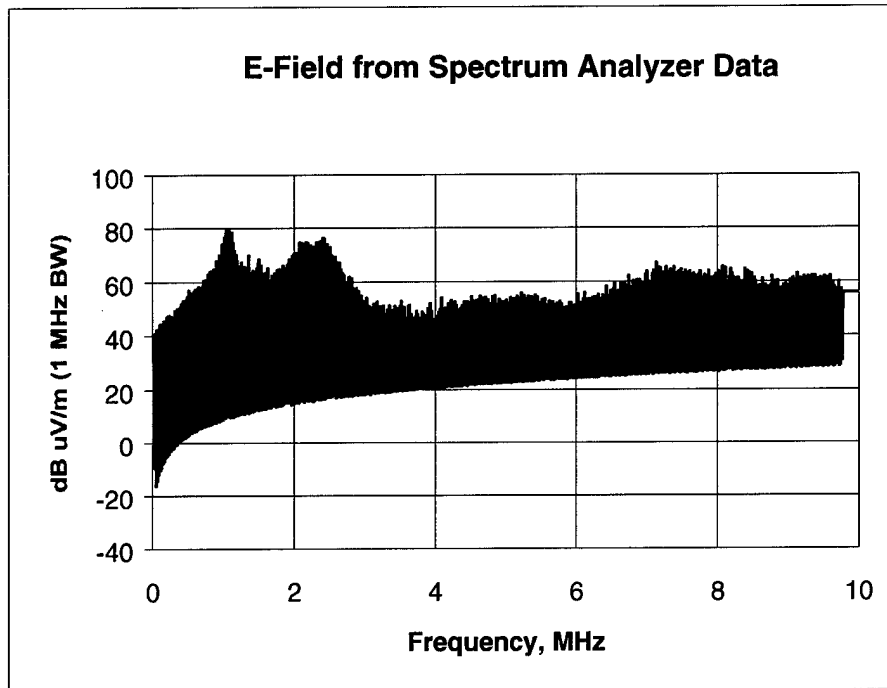Figure 18. Determination of electric field from spectrum analyzer data.

Figure 19. Reliance Motor Controller electric field (frequency domain).

ELECTRIC FIELD FROM TIME-DOMAIN DATA

Figure 20 shows the process used to convert the time-domain scope data to an electric field. The corrected voltage versus time waveform (figure 21) is multiplied by the GTEM transfer function at the prominent frequency of 1 MHz to obtain the field versus time. Figure 22 shows the resulting electric field, a damped sinusoid. The repetition rate of the time waveshape (not shown) is 120 microseconds.

$$E_i = 10 \ V \ f_{GHz}$$

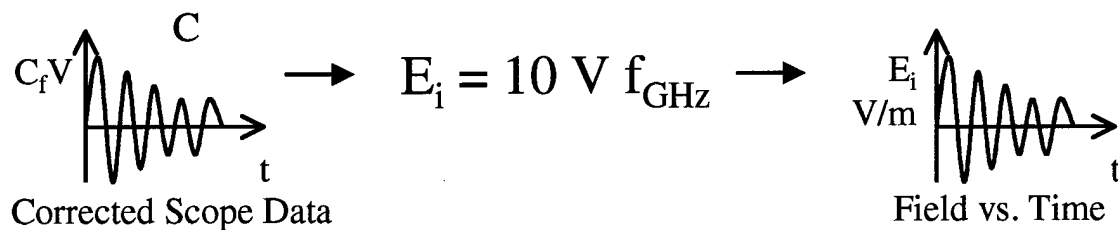Corrected Scope Data   Field vs. Time

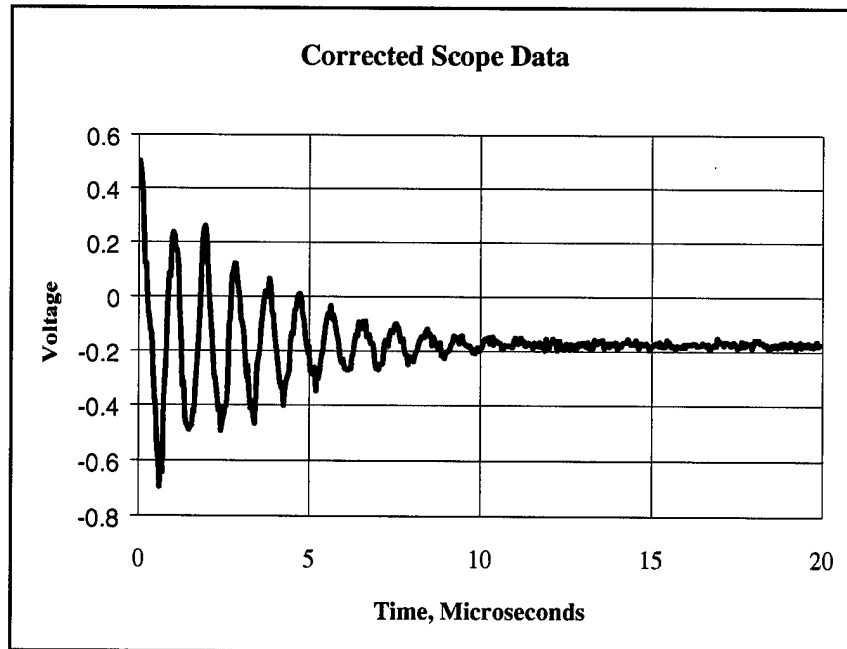Figure 20. Determination of electric field from oscilloscope data.

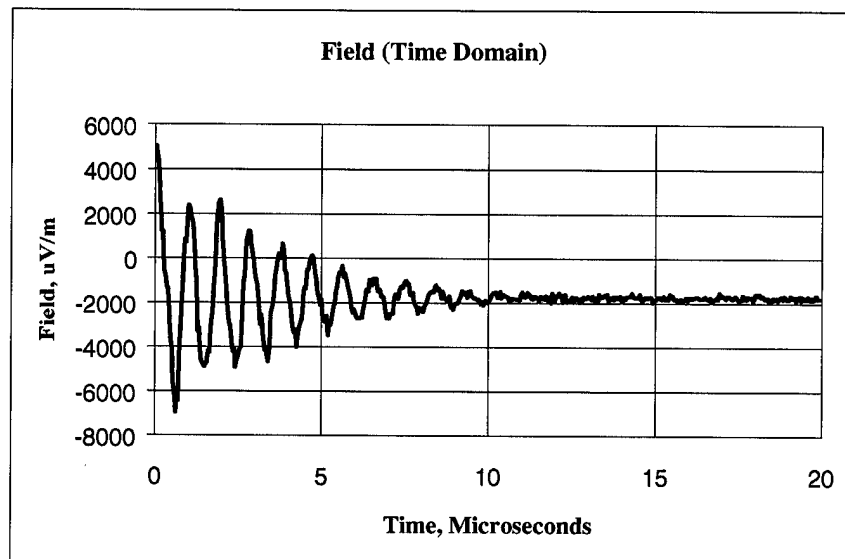Figure 21. Amplitude-corrected time data from oscilloscope.

Figure 22. Time-domain electric field.

The measured data for the electric field versus frequency in figure 19 was taken with the motor control unit running at a 50-kW load. When this load was increased to 100 kW, the measured data increased by 6 dB. The same results were noted with the time waveshape in figure 22. The load was not increased above the 100-kW level in further tests.

COMPLIANCE WITH MILITARY STANDARDS

Electrical equipment to be used by the Navy is subject to Military-Standard-461/-462 limitations. Other commercial standards may apply depending on the equipment's intended use. In figure 23, the radiated emissions limit specified by MIL-STD-461D has been superimposed on the graph of the measured electric field. The Reliance Electric motor controller complies with these limits in the 1- to 10-MHz frequency range.
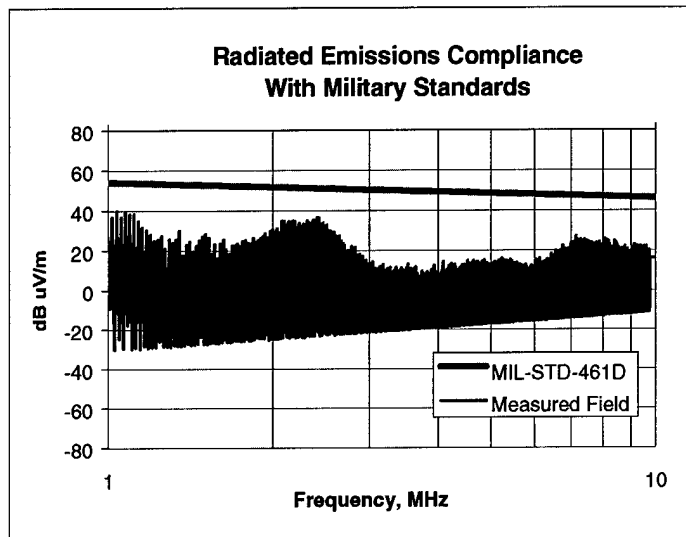
Figure 23. Compliance with military standards.

FUTURE WORK ON SUSCEPTIBILITY MEASUREMENTS

The GTEM is a useful tool for measurement of EMI from power-generating equipment (radiated emission type tests). The GTEM can also be used to generate electric fields for susceptibility tests but was not exercised in this mode for the motor controller tests. GTEM data could be used to generate shielding requirements or to characterize a series of susceptibility tests that could determine the vulnerabilities of other equipment to the EMI generated by power switching (figure 24).
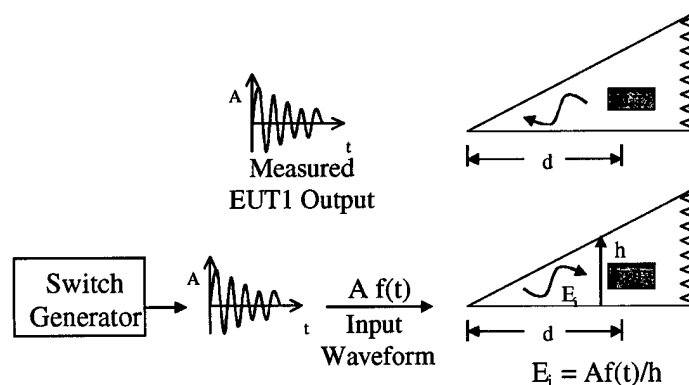
Figure 24. Susceptibility testing.

The waveform generated by switching events could be reproduced by the switching circuitry or other means and used as an input to the GTEM. The amplitude of the incident electric field generated in the GTEM would be defined at the location of the EUT and made equal to the electric field predicted at the location of the victim equipment. Since the measured electric field from EUT1 is a function of distance, d, an electric field at this location of any victim equipment relative to d can be determined. This electric field can then be replicated at the location of the victim equipment, EUT2, in figure 24. These EMI tests would be very meaningful since they would consider an actual predicted environment because of a given equipment configuration instead of taking standard EMI measurements. The frequency versus amplitude plots required by standard EMI tests cannot produce this type of test data. GTEM measurements using equipment such as spectrum analyzers can also provide the frequency versus amplitude data taken in standard EMI testing. These data could be used to satisfy standard requirements.

SUMMARY AND CONCLUSIONS

The GTEM measurement facility built by SSC San Diego was successfully demonstrated in the characterization of a hard-switching motor controller for EMC considerations. The emissions of the Reliance Electric GP2000 motor controller were measured in both the time and frequency domains. The measured data were processed to provide the electric field generated by the equipment under test.

The measured data indicate that the Reliance unit meets the Military Standard (MIL-STD-461D) specifications for radiated emissions for frequencies between 1 and 10 MHz. Although the Reliance unit is not necessarily intended for shipboard application, this reference provides a benchmark against which the PEBB units may be compared. The Reliance unit is an example of hard switching while the PEBB units are to incorporate soft switching, which should help reduce EMI. The GTEM cell measurements will allow a comparison between various switching techniques.

The next series of tests should involve actual PEBB prototypes. It is anticipated that future tests on PEBB-type units would employ the DC power supply and the water-cooling unit that were procured for PEBB testing. Since no PEBB units were available when this task was performed, the DC power supply and water-cooling unit were not tested. The complete facility will be put on-line when the PEBB units become available.

This set of measurements demonstrated the efficiency of acquiring the data using the GTEM cell. The data acquisition itself took less than 5 minutes per measurement. The setup of the motor controller and the equipment required to operate it were the most time-consuming The speed of the data acquisition is well-suited for measurement of power electronics devices since heat generation is minimal.

Another benefit of the GTEM facility is that it allows measurement of the equipment's radiated emissions in the time domain. The time-domain measurements of the electric field are made possible by the wide bandwidth (9 kHz to 5 GHz) of the GTEM cell. Time-domain data are not generally measured in standard EMI tests because the measurement techniques (with the exception of those employed in the GTEM) are largely limited by frequency band. Time-domain data show the nature of electromagnetic interference generated by the equipment through various switching operations, valuable information that should help the PEBB equipment designer.

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REFERENCES

Divan, Deepak. 1996. "Low-Stress Switching for Efficiency," *IEEE Spectrum* (Dec), pp. 33–39.

Hockanson, D. M., J. L. Drewniak, T. H. Hubing, T. P. Van Doren, F. Sha, and M. J. Wilhelm. 1996. "Investigation of Fundamental EMI Source Mechanisms Driving Common-Mode Radiation from Printed circuit Boards with Attached Cables," IEEE Transactions on Electromagnetic Compatibiility, vol. 38, no. 4 (Nov), pp. 557–575.

Montrose, M. 1996. *Presented Circuit Board Design Techniques for EMC Compliance.* IEEE Press, New York, NY.

Krause, J. D. 1950. *Antennas.* McGraw-Hill. New York, NY.

International Telephone & Telegraph Corporation. 1975. *Reference Data for Radio Engineers*, Sixth Edition. H. W. Sams & Co., Indianapolis, IN.

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13. ABSTRACT (Maximum 200 words)

The GTEM measurement facility built by SSC San Diego was successfully demonstrated in the characterization of hard-switching motor controller for EMC considerations. The emissions of the Reliance Electric GP2000 motor controller were measured in both the time and frequency domains. The measured data were processed to provide the electric field generated by the equipment under test.

The measured data indicate that the Reliance unit meets the Military Standard (MIL–STD–461D) specifications for radiated emissions for frequencies between 1 and 10 MHz. Although the Reliance unit is not necessarily intended for shipboard application, this reference provides a benchmark against which the Power Electronics Building (PEBB) units may be compared. The Reliance unit is an example of hard switching while the PEBB units are to incorporate soft switching, which should help reduce EMI. The GTEM Cell measurements allow a comparison between various switching techniques.

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